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Assessment of long-term and large-scale even-odd license plate controlled plan effects on urban air quality and its implication

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HIGHLIGHTS

- Effect of even-odd license plate controlled plan on urban air quality was studied.
- A new method quantifying the traffic control results was developed.
- Impact of the control measures on AQI and O_3 concentrations was less.
- CO, NO_2/SO_2 and $PM_{2.5}$ have large decreases of 15–23% due to traffic controls.

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ABSTRACT

To solve traffic congestion and to improve urban air quality, long-lasting and large-scale even-odd license plate controlled plan was implemented by local government during 20 November to 26 December 2016 in urban Lanzhou, a semi-arid valley city of northwest China. The traffic control measures provided an invaluable opportunity to evaluate its effects on urban air quality in less developed cities of northwest China. Based on measured simultaneously air pollutants and meteorological parameters, the abatement of traffic-related pollutants induced by the implemented control measures such as CO, $PM_{2.5}$ and PM_{10} (the particulate matter with diameter less than 2.5 μm and 10 μm) concentrations were firstly quantified by comparing the air quality data in urban areas with those in rural areas (uncontrolled zones). The concentrations of CO, NO_2 from motor vehicles and fine particulate matter ($PM_{2.5}$) were shown to have significant decreases of 15%–23% during traffic control period from those measured before control period with hourly maximum CO, $PM_{2.5}$, and NO_2/SO_2 reduction of 43%, 35% and 141.4%, respectively. The influence of the control measures on AQI (air quality index) and ozone was less as compared to its effect on other air pollutants. Therefore, to alleviate serious winter haze pollution in China and to protect human health, the stringent long-term and large-scale even-odd license plate controlled plan should be implemented aperiodically in urban areas, especially for the periods with poor diffusion conditions.

1. Introduction

It has been estimated that 90% of urban air pollution is attributed to vehicle emissions in fast-growing cities of developing countries (UNEP, 2010). As the primary measure to improve urban air quality, long-term or short-term (several hours) even-odd license plate controlled measures adopted by traffic management

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during several important events such as the 2014 Asia-Pacific Economic Cooperation (APEC) summit have been shown to be an effective measure of emission reduction (Chen et al., 2015; Hao et al., 2011; Huang et al., 2015; Li et al., 2010; Liu et al., 2016; Schleicher et al., 2011, 2012; Sun et al., 2016; Wang and Xie, 2009; Wang et al., 2010; Wang and Dai, 2016; Worden et al., 2012; Zhao et al., 2014a, 2014b; Zhao and Yu, 2017; Zhou et al., 2010). For example, all aerosol species and NO_2 columns were shown to have significant decreases of 40–80% during APEC from those measured before APEC (Chen et al., 2015; Liu et al., 2016; Sun et al., 2016). The SO_2, NO_2, PM_{10}, and $PM_{2.5}$ concentrations during APEC period in Beijing decreased by 62%, 41%, 36%, and 47%, respectively, whereas O_3 concentration increased by 102% compared with the same time period in the previous 5 years (Wang et al., 2015). The Artificial Neural Network (ANN) models were used by Li et al. (2016) to predict the pollutant concentrations during APEC without the emission control measures, and the results prove that $PM_{2.5}$ and PM_{10} were reduced by 24% and 28%, respectively. However, the emissions from other sources were also controlled during the events, which will interfere to assess traffic control impacts. Furthermore, only 10 traffic-restricted days for APEC were too short to accurately assess traffic control impacts. The favorable weather conditions were also helpful to diffusion of air pollutants during the control periods and thus the interference of weather conditions was not better eliminated in the studies. Furthermore, the previous measures were mainly concentrated on more economically developed eastern coastal cities of China. The energy structure and economic development level largely varied from the developed cities to the cities of northwest China. Until now impact of the even-odd license plate controlled plan with increased public transport vehicles on urban air quality remains poorly known in less economically developed cities of northwest China despite its potential to be a mitigation measure for air pollution.

To effectively alleviate severe air pollution induced by more primary emissions and frequent temperature inversion in winter (Tang et al., 1985; Zhang et al., 2000), the long-term and large-scale even-odd license plate controlled plan was taken in the winter of 2016 in urban Lanzhou. Regardless of model year, make, fuel type and class, etc., the small and micro passenger cars with 9 seat or less and odd (even) license plate numbers were controlled on city roads throughout the even (odd) days during 20 November to 2 December 2016 and those were controlled only from 07:00 to 22:00 of even (odd) days during 3–26 December 2016. Half of the passenger cars were reduced for the days of the restricted period. Additionally, the taxi and public transport vehicles were strengthened during the period. 314 city buses were increased and their working time was prolonged by ~3 h every day in downtown areas. The first (last) bus every day was earlier (later) during the control period than during non-control period. Furthermore, the buses were free for the citizens to reduce the pollutants emitted from vehicles. The even-odd license plate controlled plan provided an invaluable opportunity to study the traffic control effects in a heavily congested and densely populated valley city in northwest China. Fig. 1 shows the traffic-restricted zones and the monitoring sites of air pollutants and meteorological parameters in Lanzhou.

The key objective of this study is to evaluate the effect of the long-term and large-scale even-odd license plate controlled plan on urban air quality, especially CO, NO_2 and fine particulate matter ($PM_{2.5}$, particles with diameter less than 2.5 μm). Lanzhou, located in the northwest of China, was less affected by the super-city clusters such as Jing-Jin-Ji areas and Yangtze River Delta, which is helpful to assess the traffic control impacts. The contribution of even-odd license plate controlled plan to reduced gases and particulate matter pollutants was quantified by comparing air quality and meteorological data between urban and rural areas of Lanzhou. The study is expected to provide a basis for the formulation of future urban air pollution control measures.

2. Data and methods

2.1. Air quality data

2.1.1. Arrangement of monitoring sites

Lanzhou, located in a long valley runs mainly from the east to the west with a length of about 30 km, maximum width of 8 km, and depth of 200–600 m, is a typical valley city in an arid area with a population of approximately 3.5 million and the annual rainfall of ~327.7 mm and mean temperature of ~9.3 °C. Due to effect of the valley terrain, mean surface wind speed is only ~0.3 m s^{-1} in winter, and the monthly calm frequency reaches as high as 81% (Wang et al., 1999). Furthermore, a lot of industries are based in Lanzhou including an oil refinery, petrochemical industries, machinery and metallurgical industries, textile mills, food processing centers, cement manufacturing, coal mining, rubber processing, electrical power generation, medical industries, lead and zinc mining and smelting and fertilizer plants (Zhang et al., 2012). The air pollutants emitted from the industries were difficult to disperse due to weak winds and stable stratification inhibiting turbulent diffusion aspect with the aspect ratio of the valley (depth versus width) of ~0.07 (Chu et al., 2008).

The hourly mean concentrations of six criteria air pollutants ($PM_{2.5}$, PM_{10}, CO, SO_2, NO_2 and O_3) in 74 major Chinese cities have been released by China National Environmental Monitoring Center since January 2013 (Zhao et al., 2016). The state-controlled monitoring sites were selected to reflect a large diversity of potential sources of air pollution variability (e.g., population density, traffic intensity, industry, and geographical and climatic conditions). The environmental conditions around the monitoring sites were relatively stable to avoid other effects such as torrential flood and mud-rock flows. The horizontal distance between monitoring port and the highest obstacle near it should be more than double their height difference to keep well-ventilated near the sampling sites. Additionally, the sampling port or monitoring beam was 3–20 m above the ground surface for automatic monitoring, and the distance between sampling port and building wall body or rooftop should be larger than 1 m when the instrument was installed above the building. For the urban monitoring sites, there were not obvious stationary pollution sources in 50 m around the sampling ports to better assess urban air quality. The minimum intervals between sampling port and roadway were limited based on daily mean traffic flow to avoid the direct effects of motor vehicle exhaust on monitoring results.

The five state-controlled monitoring sites of Lanzhou were shown in Fig. 1. (1) LLBG (36° 6′ 11.00″ N, 103° 37′ 51.00″ E) in the Xigu District, an industrial area with an oil refinery company, petrochemical plant, textile mill, and other small industries; (2) ZGYY (36° 4′ 32.00″ N, 103° 42′ 43.00″ E) in the Qilihe District, residential and commercial areas near the Lanzhou Petro-Chemical Machinery Plant, which produces large machines for oil production; (3) SWZPS (36° 4′ 21.00″ N, 103° 50′ 28. 00″ E) in the Chengguan District, a residential area near the Lanzhou Institute of Biological Products, which performs research and manufacturing of biological products; (4) TLSJY (36° 2′ 47.00″ N, 103° 49′ 52.00″ E) in the Chengguan District, residential and commercial areas near a